NAVAL HEALTH RESEARCH CENTER

GENDER DIFFERENCES IN FINGER TEMPERATURES DURING COLD AIR EXPOSURE

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Report No. 97-37

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BETHESDA, MARYLAND

Gender differences in finger temperatures during cold air exposure

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Report No. 97-37, supported by the Naval Medical Research and Development Command, Department of the Navy, Bethesda, Maryland under Work Unit Number 63706N M0096.002-6603. The views expressed in this paper are those of the authors and do not reflect the official policy or position of the Department of the Navy, the Department of Defense, or the U.S. Government. Approved for public release, distribution is unlimited.

Human subjects participated in this study after giving their free and informed consent. Investigators adhered to NAVHLTHRSCHCENINST 6500.2, 2 Aug 95, concerning the protection of human volunteers in medical research.

Summary

Problem

Exposure of the fingers to cold air during work and exercise can lead to a decrement in function and increase the risk for cold injury. Although many women are involved in activities that impose a risk of cold injury, the ability of women to resist these effects during cold exposure is unknown.

Objective

The purpose of this study was to compare finger temperatures (T_f) of women and men exposed to 0°C air for up to 135 min (15 min with mittens on, and up to 120 min with mittens off).

Approach

Each subject participated in four trials. Active-duty U.S. Navy personnel (nine women and nine men) wore warm winter clothing during each trial, sat with their arms supported at heart level, hands laying on an open mesh surface. T_f was measured and recorded every min from the dorsal aspect of each finger just proximal to the nail bed. Due to removal of subjects before 135 min, analyses were performed on only the first 75 min of cold air exposure.

Results

In all T_f, men were significantly warmer ($p < 0.05$) than women between minute 0 and minute 40. Cold induced vasodilation (CIVD) occurred in both men and women.

Conclusion

Our findings suggest that short-term exposure to cold may place women at a greater risk for cold injury to the fingers than men.

Introduction

Many military tasks require manual dexterity, finger flexibility, and tactile sensitivity. Any condition that interferes with these physical abilities will negatively impact the ability to perform manual tasks. Under normal cold (<5°C) air conditions, military personnel will work while dressed for cold exposure but may have to perform job tasks requiring manual dexterity. When hands and fingers are exposed to cold stress, increased fluid viscosity in joints reduces dexterity and flexibility, and cooling nerve tissues reduces tactile sensitivity. One physiological mechanism for maintenance of these physical abilities is to increase peripheral blood flow subsequently transferring heat from the body core to the fingers. Therefore, the presence and strength of this peripheral action during cold stress may be a good indicator of an individual's ability to perform certain military tasks under those environmental conditions.

When a person is exposed to a cold environment, a sympathetic nervous system-induced cutaneous vasoconstriction occurs, causing a decrease in body heat loss to the environment (Havenith et al. 1995). When cold air exposure is moderate and localized to the hands, as with removal of hand protection, core body temperature can remain unchanged (Roberts and Berberich 1988), but the hands will exhibit some degree of vasoconstriction (Havenith et al. 1995; Toner and McArdle 1988). Peripheral vasoconstriction is not dependent entirely on decreased body core temperature but is more likely to occur because individuals remove protective gear to perform necessary tasks for job performance or, in extreme cases, survival.

When peripheral vasoconstriction occurs, the temperature of the extremities decreases. When extremity temperatures reach approximately 15°C (varies among individuals), effective use of the digits is compromised (Daanen 1993; Heus et al. 1995) leading to a reduced ability to perform tasks and increased risk of peripheral cold injury. As the finger temperature (T_f) approaches 10° C, a cold-induced vasodilation (CIVD) can occur, causing an increase in T_f (Roberts et al. 1980). The CIVD opens peripheral blood vessels to provide increased blood flow

to the extremities. While much is known about CIVD and its role in modifying the peripheral response to cold exposure in men (Adams and Smith 1962; Edwards 1967; Edwards and Burton 1960; Fox and Wyatt 1976; Livingstone 1976; Teichner 1966), no comparable information exists concerning CIVD in women during cold exposure. Physiological differences between the genders could result in the inability of women to maintain sufficient extremity blood flow; maintain T_f, finger strength, and manual dexterity; or to produce sufficient rewarming (by increasing blood flow) when their extremities get cold.

The Presidential Commission on the Assignment of Women in the Armed Forces has recommended that the military adopt a gender-neutral assignment policy (Presidential Commission 1993). The Secretary of the Navy has recommended expanding the number of jobs open to women including the assignment of women on all fleet ships. Since both the U.S. Navy and the U.S. Marine Corps have units with cold weather missions, women assigned to these units will be exposed more often to varying degrees of cold stress.

When military cold weather clothing is worn correctly, individuals can remain warm even in severe weather. The problem lies in the difficulty of performing tasks that require a high degree of manual dexterity while wearing heavy gloves or mittens. The usual practice is to remove the heavy gloves and perform tasks with little or no hand protection, leaving the hands exposed to the cold and increasing the risk of cold injury.

While several studies (Bartelink et al. 1990; Folkow et al. 1963; Wagner and Horvath, 1985) have reported gender differences in thermoregulatory responses to cold, a controversy exists concerning the effect of the menstrual cycle on thermoregulation during cold exposure. It has been reported that pre- and post-ovulatory women have the same thermal responses to cold exposure (Bartelink et al. 1993; Cunningham et al. 1978). In a warm environment, higher core body temperature is maintained during the luteal phase and a 12 % increase in finger blood flow occurs during the follicular phase in non-exercising women (Bartelink et al. 1990; Ware and Smith

1994). Since peripheral blood flow is the main source of heat for the extremities, menses could affect the rate of cooling and T_f

The purpose of this study was to assess gender differences in the effect of a cold air exposure on limiting performance and increasing cold injury risk in women. Four hypotheses were to be tested: first, that with cold exposure, the T_f of women would be the same as the T_f of men. Second, that at similar T_f, ability to perform digital dexterity, fine-motor movements and strength in the cold would not differ between genders. Third, during the follicular phase of the menstrual cycle, T_f would be higher than the luteal phase. Finally, during the luteal phase, women would not demonstrate a CIVD response.

Methods

Nine men and nine women U.S. Navy and U.S. Marine Corps personnel participated as subjects. All measurements and methods were approved by the Naval Health Research Center and the Naval Medical Research and Development Command Committees for the Protection of Human Subjects.

Subjects were informed of the nature, purpose, and potential risks of the experimental procedures and signed an Informed Consent document. All subjects underwent medical screening, including a review of medical history, and were cleared to participate by a medical officer. As part of the medical screening, and prior to each trial, women subjects were tested for pregnancy by determining the presence of urinary human chorionic gonadotropin. Pregnant women were not allowed to participate in the study. Height and weight were determined using stadiometry and an AND HV-150K electronic scale, respectively. Body density was determined from hydrostatic weighing with residual lung volume determination (Buskirk 1961), and the Siri (1961) equation was used to estimate percent body fat.

The womens' physical characteristics were ($\bar{X} \pm SD$): weight 67.2 ± 7.5 kg, height 163.6 ± 5.9 cm, percent fat 26.9 ± 6.8%, lean body weight 48.8 ± 4.7 kg, fat weight 18.4 ± 5.8 kg, and maximal oxygen consumption from a treadmill graded exercise test ($\dot{V}O_{2max}$) 34.8 ± 6.1 ml • kg^{-1} • min^{-1}. The mens' physical characteristics were ($\bar{X} \pm SD$): weight 86.0 ± 12.4 kg, height 182.2 ± 6.0 cm, percent fat 17.6 ± 7.2%, lean body weight 70.1 ± 6.7 kg, fat weight 15.9 ± 8.0 kg and $\dot{V}O_{2max}$, 45.2 ± 6.0 ml • kg^{-1}•min^{-1}. There were significant ($p < 0.05$) differences between genders for all of the physical characteristics.

Experimental Protocol

Subjects reported to the laboratory on five separate days. On day one, subjects were familiarized with the laboratory, the equipment, and the procedures to be used; underwent medical screening, hydrostatic weighing and $\dot{V}O_{2max}$ determination; and were given time to learn a finger pinch strength (FPS) test, and hand dexterity (knot-tying) tests. The knot-tying test was a 1-min timed test (number of knots tied in 1-min) using only the dominant hand with the elbow on an arm rest. The FPS test involved lifting a progressively incremented weight to a height of 76 mm with the non-dominant hand's thumb and index finger and with the elbow resting on the arm rest. The heaviest weight lifted to 76 mm was recorded. In order to keep activity from affecting T_f, the knot-tying and FPS were performed only twice, once when the fingers were first exposed to the cold and again at the end of cold exposure but while still in the cold.

For women, to account for possible variation in core temperature due to menses, two cold exposure trials were conducted during the follicular phase of the menstrual cycle and two during the luteal phase. Follicular phase was determined as 7-9 days after menstruation began and luteal phase was determined as 16-18 days after menstruation began. Onset of menses was monitored for two months to establish cycling pattern. If a woman did not have a regular menstrual cycle,

trials were conducted approximately 14 days apart. For men, trials were conducted approximately 14 days apart. The influence of circadian rhythms on body temperature was controlled by conducting each test at the same time of day.

All trials were conducted in a temperature-controlled environmental chamber at 0°C, 80% relative humidity, and wind speed 1.5 kt • h^{-1}. Exposure duration was scheduled for maximum of 135 min. Prior to entering the chamber, the subject was instrumented for measuring core body temperature using a thermistor (Sher-I-Temp®) inserted 15 cm into the rectum. Rectal temperature (T_{re}) was used to verify similar core body temperatures at the start of each trial and to monitor any changes during each trial. Skin temperature (T_{sk}) and T_f were measured using silver skin thermistors (Science/Electronics). T_{sk} was recorded at six sites (chest [T_{chest}], forehead [$T_{forehead}$], back [T_{back}], hand [T_h], anterior thigh [$T_{anterior\ thigh}$], and lateral calf [$T_{lateral\ calf}$]). A Grant 1200 series (12-bit) Squirrel Meter/Logger was used to record T_{re}, T_f, and T_{sk}. Mean weighted skin temperature ($\bar{T}_{sk}$) was calculated using the equation of Nishi and Gagge (1970): $\bar{T}_{sk} = 0.175T_{chest} + 0.225T_{forehead} + 0.18T_{back} + 0.005T_h + 0.195T_{anterior\ thigh} + 0.22T_{lateral\ calf}$. T_f for each finger was measured by silver skin thermistors placed on the dorsal aspect of the finger just proximal to the nail bed. The subject, dressed in military cold weather clothing with mittens, was seated in the chamber with the hands supported at heart level on an open-mesh screen. After 15 min in the chamber, the heavy mittens were removed, exposing the hands to the cold. Immediately after mitten removal, the subject completed a knot-tying test with the dominant hand and a FPS test with the non-dominant hand.

Following the performance tests, the subject was instructed to keep the hands stationary on the open mesh. At the end of 120 min of hand cold exposure or when the subject reached an end point (T_{sk} = 5°C or the subject voluntarily terminated the exposure), the performance tests were repeated and the trial ended.

Statistical Analysis

All four trials were used for comparison between men and women. All subjects completed at least 75 min of exposure, therefore, for all temperature measurements, only the first 75 min of exposure were used (15 min gloves on, 60 min gloves off). For the dexterity and strength test, beginning and ending scores were used. Temperature data were analyzed using repeated-measures analysis of variance. Analyses were conducted using eight time points: -15 min, when the subject first entered the cold chamber with mittens on; 0 min, the last minute with gloves on; 10 min, an average of minutes 0 to 10; 20 min, an average of minutes 11 to 20; 30 min, an average of minutes 21 to 30; 40 min, an average of minutes 31 to 40; 50 min, an average of minutes 41 to 50; and 60 min, an average of minutes 51 to 60. With all four trials used for comparison, FPS and dexterity were analyzed using a repeated measures ANOVA comparing pre, when the gloves were first removed, and post, just before the subject was removed from the cold. The alpha level was set at 0.05. When significant differences occurred, a Neumann-Kuels post hoc analysis was used to determine where differences occurred. All variables are expressed as $\bar{X} \pm SD$.

Results

There were significant differences between genders in all right hand T_f at minutes 10, 20, and 30, except at minute 30 for the middle finger, with men having higher temperatures. In addition, there was a significant difference in T_f among the right middle, ring, and little fingers at minute 0 and the thumb at minute 40 again with mens' fingers being higher. No significant differences in any T_f were found after 40 min. There were significant differences between genders in all left hand T_f at minutes 0, 10, 20, and 30. As a representative pattern of T_f during cold exposure, the right ring T_f is shown in Figure 1. Over the first 60 min of cold hand exposure,

women had a significantly lower temperature for each finger compared with men. Average right hand T_f for women and men is shown in Figure 2 and the left hand in Figure 3. During the cold exposure, both genders experienced T_f fluctuations representative of CIVD. Figure 4 is an example of the T_f fluctuation in one man and one woman for the right index finger.

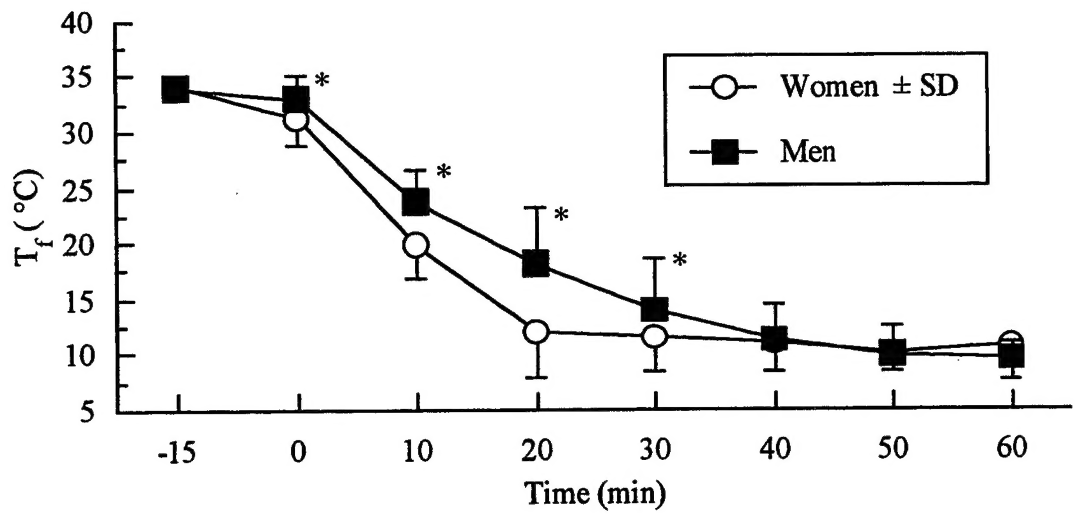

Fig. 1 Right ring finger in men and in women ($\bar{X}$ ± *SD*). * Indicates a significant difference ($p < 0.05$) between the genders.

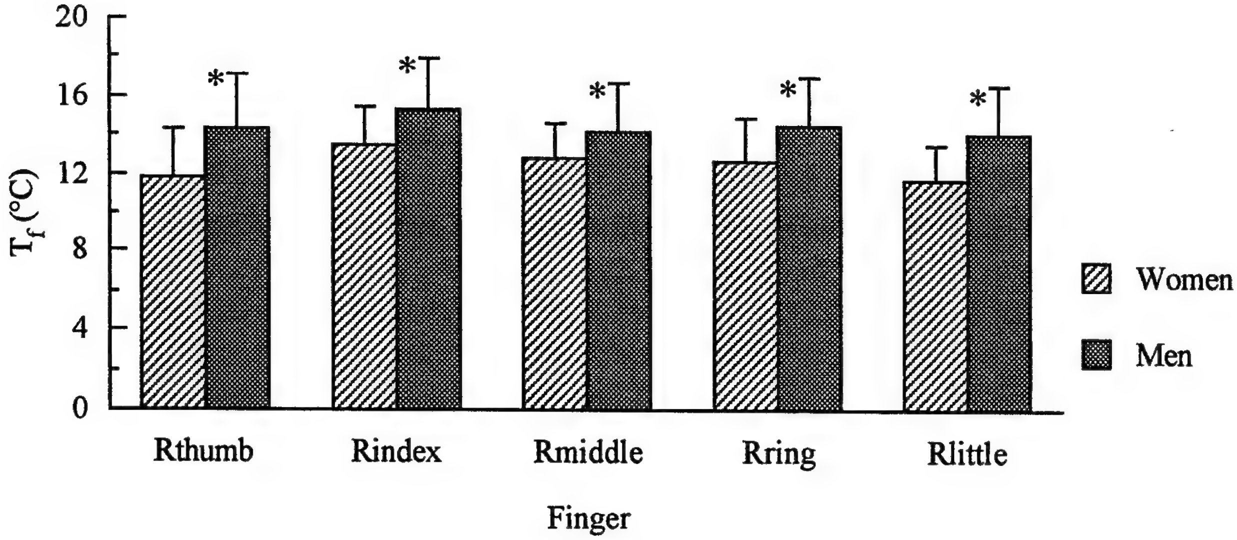

Fig. 2 Right hand mean finger temperature over a 60-min exposure to 0°C in women and in men ($\bar{X} \pm SD$). * Indicates a significant difference ($p < 0.05$) between the genders.

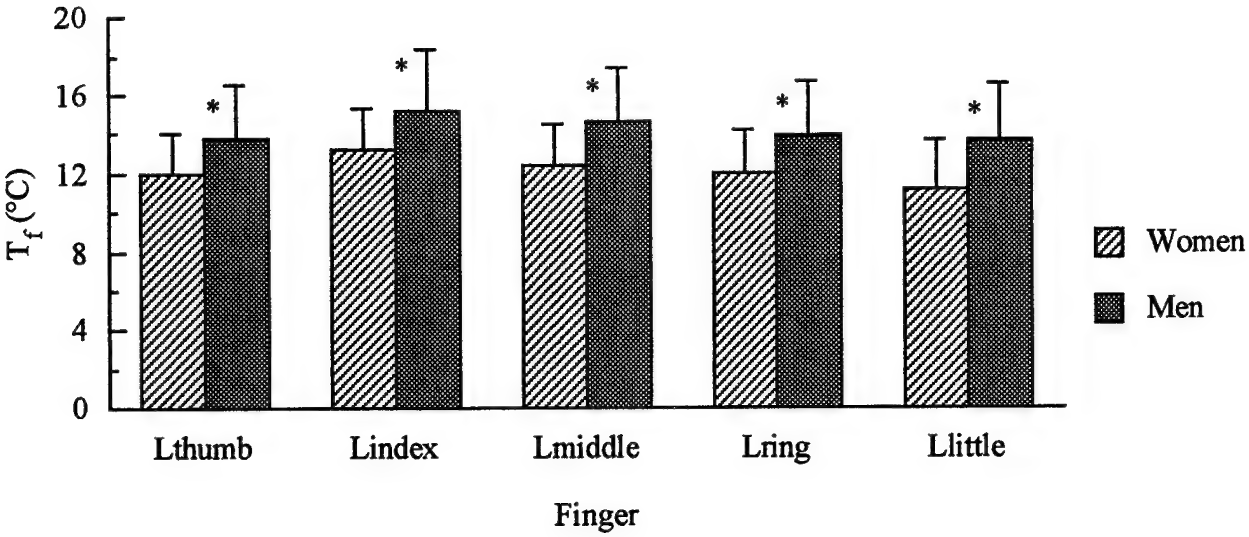

Fig. 3 Left hand mean finger temperature over a 60-min exposure to 0°C in women and in men ($\bar{X} \pm SD$). * Indicates a significant difference ($p < 0.05$) between the genders.

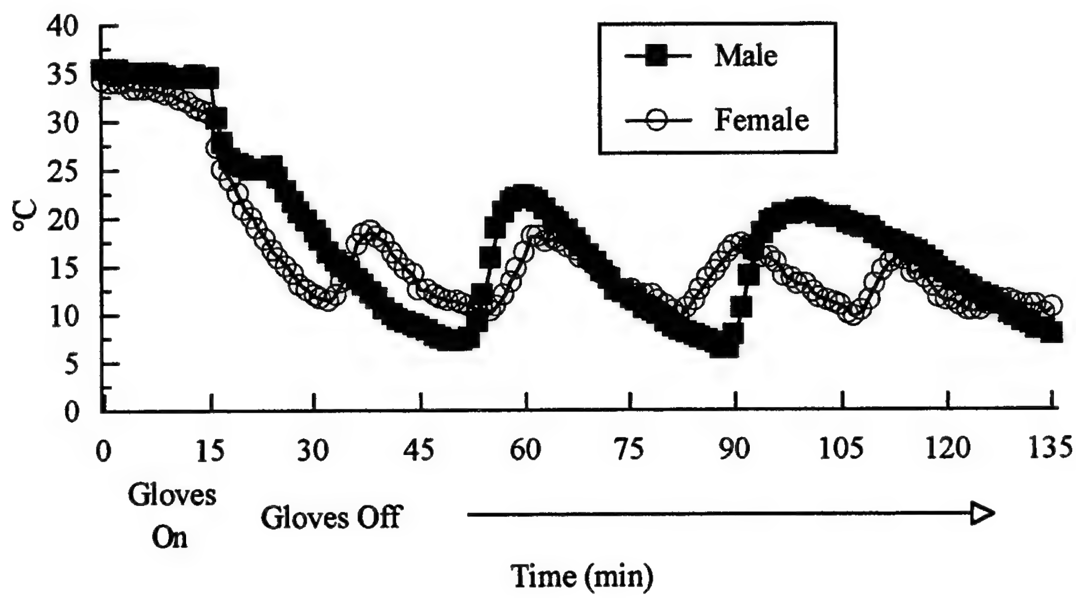

Fig. 4 Finger temperature pattern consistent with CIVD. Example of one man and one woman's right index finger response to 0°C cold exposure.

Analysis of T_{re} and $\bar{T}_{sk}$ revealed no significant differences between genders. A significant decrease in $\bar{T}_{sk}$ over time, from 0 min to 75 min, occurred for women (31.8 ± 0.9 °C to 30.7 ± 1.0 °C) and for men (32.0 ± 0.9 °C to 31.2 ± 0.8 °C). Analysis of T_h (Figure 5) revealed no differences between genders and accounted for most of the decrease in $\bar{T}_{sk}$. A gradual, but significant, decrease occurred in T_h over time.

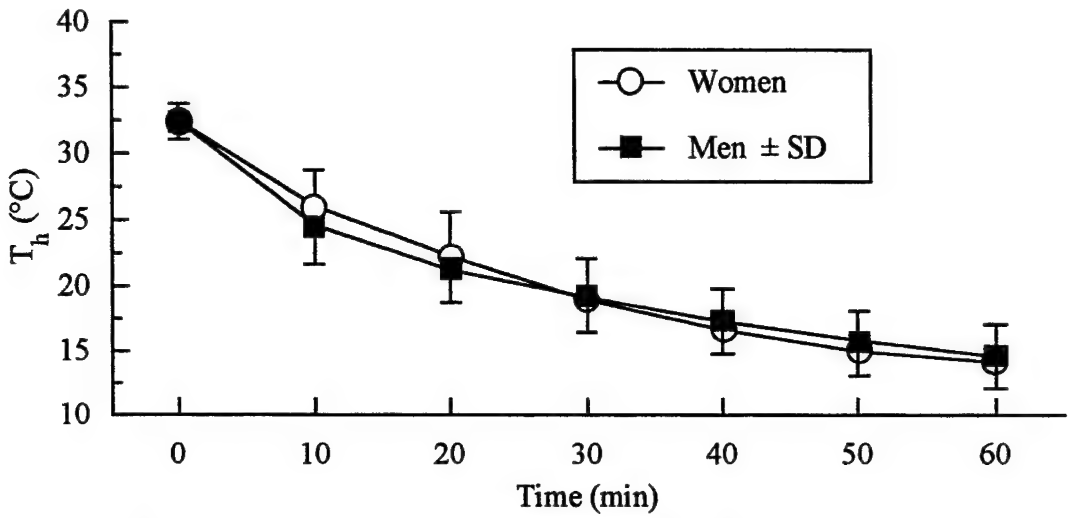

Fig. 5 Hand temperature for men and women ($\bar{X}$ ± *SD*). No gender difference was seen.

The average duration of cold exposure for women (111 ± 23 min) and men (112 ± 22 min) were not different. Of 72 trials, 9 (12.5%) were stopped short of the 135 min due to T_f at or below 5°C and 24 (33.3%) were stopped short of 135 min due to voluntary withdrawal usually for extreme discomfort in the digit(s). Analysis of the knot-tying task (Table 1) revealed no gender difference with both significantly decreasing pre to post. FPS (Table 1) was greater in men in both pre and post with no significant difference between genders in the decrease from pre to post.

Table 1. Knot-tying and FPS test results (* $p < 0.05$ between genders).

Test	Time	Women (± SD)	Men (± SD)
Knot-tying	Pre	$5.7 \pm 3.1 \cdot min^{-1}$	$6.1 \pm 2.0 \cdot min^{-1}$
Knot-tying	Post	$1.6 \pm 1.7 \cdot min^{-1}$	$1.8 \pm 1.6 \cdot min^{-1}$
FPS	Pre	2.2 ± 0.3 kg*	2.8 ± 0.4 kg*
FPS	Post	1.5 ± 0.4 kg*	1.9 ± 0.7 kg*

Discussion

This study was performed to determine if there are gender differences in the peripheral responses to cold exposure. In this study, the temperature data analyses were limited to the first 75 min of the total 135-min exposure. This was necessary to include subjects who could not complete the full exposure duration. However, the T_f of both groups had reached the same temperature by min 40, remaining relatively stable thereafter.

McArdle et al. (1984) reported that the peripheral response to cold can be affected by changes in core temperature. It also has been reported that men respond to cold stress by increasing blood flow to their extremities and allowing their core temperature to decrease (Sato et al. 1988). Women, on the other hand, respond to cold stress by decreasing blood flow to the periphery in an attempt to conserve body heat (Stevens et al. 1987). These studies would suggest that women would have colder hands and feet during cold stress than men. Under the cold stress conditions of the present study, this was confirmed. While T_{re} did not change over time, the womens' fingers cooled significantly faster during the initial 40 min of cold exposure

than mens' fingers. This indicates that the increased rate of finger cooling seen in the women was not due to a difference in core body cooling but rather was due to a gender difference in the peripheral response to the cold stress.

The finding of stabilized T_f after 40 min is likely due to the combined driving force of the cold stress and the subjects' inactivity which did not produce muscle pumping action in the forearm to move warm blood into the fingers. The experimental conditions in this study mimic situations that could occur when military personnel are forced into an inactive role during cold weather operations.

Both women and men experienced significant decrements in the ability to use their fingers during the finger strength and knot-tying tasks by the end of exposure, indicating that neither group would have a long-term advantage in the ability to use their fingers in a cold environment. Similar decrements in strength of the same magnitude seen in this study were recorded on a hand dynamometer when T_{sk} dropped to approximately 10° C (Kay 1949). These performance decrements indicate that the CIVDs seen did not keep the fingers at a temperature sufficient to maintain full function. To maintain fully functional fingers, it is evident that either increased thermal protection or an external heat source is required when activity is limited or increased whole body or regional metabolic activity is not possible.

Ware and Smith (1994) reported increased skin blood flow during the follicular phase of the menstrual cycle when measured in a thermoneutral environment. During cold stress this could result in colder fingers for women during the luteal phase. We did not see a difference in the response to the cold stress between the phases of the menstrual cycle. This may indicate that hormone-induced thermoregulatory modulations in the periphery differ depending on the ambient temperature.

We were unable to evaluate the effect of pharmaceutical contraceptives on thermoregulation due to the small sample size. Of the nine women in the study, four women used no medications and had regular menstrual cycles, four were using oral contraceptives that produce a regular menstrual cycle, and one used Depo Provera® resulting in no menstrual cycling.

In conclusion, our findings suggest that although hand strength and dexterity degrade similarly, during short-term cold exposure (<40 min), women may be at greater risk than men for cold injury to the fingers. Women may require different hand protection systems. Future studies in this area should include determining safe exposure times for women and men performing tasks that require hand strength and dexterity in the cold, development of special gloves or hand coverings for work in the cold, and determination of the role of metabolic thermogenesis in warming cold fingers.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
12-15-97

3. REPORT TYPE AND DATE COVERED
Final 1996

4. TITLE AND SUBTITLE
Gender differences in finger temperatures during cold air exposure

5. FUNDING NUMBERS
Program Element:63706N
Work Unit Number: M0096 002-6603

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION
Report No. 97-37

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Many women are involved in activities that impose a risk of cold injury to the fingers, and the ability of women to resist these effects is unknown. The purpose of this study was to compare finger temperatures (T_f) of women and men exposed to 0°C air for up to 135 min (15 min with mittens on, and up to 120 min with mittens off). Each subject participated in four trials. Active-duty U.S. Navy personnel (nine women and nine men) wore warm winter clothing during each trial, sat with their arms supported at heart level, hands laying on an open mesh surface. T_f was measured and recorded every min from the dorsal aspect of each finger just proximal to the nail bed. Due to removal of subjects before 135 min, analyses were performed on only the first 75 min of cold air exposure. In all T_f, men were significantly warmer ($p < 0.05$) than women between minute 0 and minute 40. Cold induced vasodilation (CIVD) occurred in both men and women. Our findings suggest that short-term exposure to cold may place women at a greater risk for cold injury to the fingers than men.

14. SUBJECT TERMS
CIVD, cold injury, gender difference, cold hands, cold fingers

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited